# A Study on the Performance and Mechanism of Soil-reinforcement by Herb Root System

**Hong Cheng[1], Xiaojie Yang[1], Aiping Liu[1], Hengsheng Fu[2], and Ming Wan[2]**

[1]*Nanchang Water Conservancy and Hydropower College, Nanchang 330029, China*

[2]*Jiangxi Provincial Highway Administrative Bureau, Nanchang, 330002, China*

**Abstract:** A study is carried out on the mechanic function and the mechanism of soil reinforcement by herb root systems is discussed, in which there are four primary functions analyzed and four sorts of soil-stabilities in using herb roots are raised. An experimental comparison with mechanics in the function of soil-reinforcement of various herb roots was conducted. The results revealed that various roots have different tensile strength. Thus, the maximum of tensile strength of Vetiver grass (*Vetiveria Zizanioides*) reaches 85 mpa; secondly, Common Cetipede grass (*Eremochioa ophiuroides hack*), 27.3; White Clover (*trifolium repens*), 24.64; Late Juncellus (*Juncelles serotinus*)_24.50; Dallis grass (*paspalum dilatatum poir*), 19.74; Bahio grass (*paspalum notatum flugge*), 19.23; Manila grass (*Zoysia matrella merr*), 17.55; Bermuda grass (*Cynodon dnactylo*), 13.45. Different tensile strengths of various roots and performance of soil reinforcement are discussed and reveal that the difference is concerned with the gene variety and tissue structure. Up to the present it is quite important and necessary for us to make use of soft engineering approaches instead of hard engineering approach in all or part, so as to protect natural resources and restore the environment during peak times of primary construction in China.

**Key words:** soft bioengineering; root network; herb; soil-reinforcement; tensile strength; root-soil organic compounds

**Email contact:** Cheng Hong <Chengh88@hotmail.com> or <nclap@sina.com.cn>

## 1 INTRODUCTION

Soft bioengineering approaches are very important and effective measures to protect water and soil resources against losses and erosion. Most researchers believe that there are two ways in controlling water and soil losses and erosion: construction methods and biologic methods. Theoretically, the former is called "hard engineering approach" and the latter "soft engineering approach". What's the relation between the two? Under what circumstances is the hard one utilized and when are the two co-utilized together, and complemented? Under what circumstances can the soft approach replace or partly replace the hard one? We are sure that the concrete function exists. Some study has indicated that the main function of vegetation approaches are as follows:

1. Intercepting rainfall so as to prevent soil detachment and movement;
2. Decreasing rainfall-flow on the surface so as to prevent soil erosion on the earth-surface;
3. Protecting against foot traffic;
4. Increasing water infiltration;
5. Providing root anchors and buttresses;
6. Absorbing water and soluble substances by roots;
7. Promoting evaporation and transpiration;
8. Protecting against wind erosion.

In the course of ecology, plants are main carriers of keeping water as an ecological factor, and the root takes a role as a bridge in the continent system of moisture-root-plant-air (Kang, 1994). Depending on its pressure, the root takes part in evaporation and transpiration of plants' water and connection with air, on the other hand, it gets in touch with the molecules of water, dissolvable minerals, sticking particles, and microorganisms etc. in soil. Thus different concentrations and potential energy of moisture and salt liquid cause water gradient movement of mineral solution, substance migration and enrichment, and thus all these take part in and influence the whole changes in ecosystems. They influence moisture distribution and change, substance migration (Huang, 2000), cause the changes of weather and surroundings. So the function of roots are very important and critical.

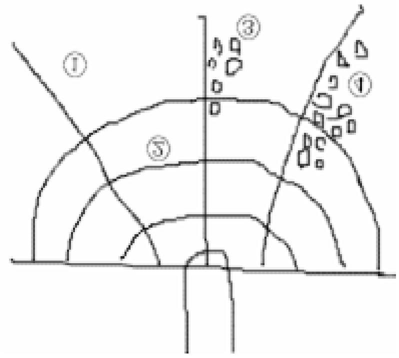
The base and conditions to realize the physiological and ecologic function is that the root should be in the soil from time to time, and as well roots should combine fully with the clay grains, colloids, organisms, minerals and microorganisms and constitute organic compounds. The root-soil compounds constitute performance of the root's soil-reinforcement and close relations of plant-soil interaction and inter-buttress. Generally, the more, the longer, the deeper and the wider the root is, the larger area it contacts, and the stronger the performance of root soil-reinforcement is. The closer the root combines with clay grains, the more substances can be sucked up and utilized by plants. Conditions and growing surroundings are mainly emphasized in general agro-forestry production and agronomy cultivation (Jackson, 1996; Gale and Grigal, 1987; Lyr and Hoffmann, 1967; Coile, 1936; Li *et al.*, 2002). Study in this field is fairly rich and ripe, but the study of reinforcement of soil by roots is largely ignored. The study of water and soil conservation stress more or less on macro research. For example, silt deposition, runoff, runoff coefficient, erosion modulus and diamond are frequently studied as far as soil and moisture are concerned, but there is sparse study on the micro mechanisms of reinforcement of soil by roots in the contact area of organisms.

Reinforcement of soil by roots includes: the ability of its mechanics and the compound integral performance of organisms between root and soil. The study of organic compounds between root and soil is hard to perform because of disturbance and mixing of the original soil. Research is mostly focusing on the physical and chemical performance of rhizosphere soil, such as active performance of root microorganism, root activeness (Liu, 1998), root ability to suck up nutrition and root growth and about facilitation of organisms and minerals(San and Tao, 1992; Song and Zhang, 1992). It is reported that the tensile strength of roots is as follows: willow (*Salix*), 9–36 mpa; Poplars (*Populus*), 5–38 mpa; Alders (*Alnus*), 4–74 mpa; Douglas fir (*Pseudotsuga*), 19–61 mpa; Silver maple (*Acer sacharinum*), 15–30 mpa; Western hemlock (*Tsuga heterophylia*), 27 mpa; Huckleberry (*Vaccinum*), 16 mpa; Barley (*Hordeum vulgare*), 15–31 mpa; Moss, 2–7 kpa; Grass, 2–20 mpa; Vetiver, 40–180 mpa. Some researchers have studied the effects of vegetation on the slope-stability, including hydrologic mechanism, mechanics. Mechanic factors indicate that plant growth increases soil load, and root function increases soil adhering (Hengchaovanich, 1999). Root works as a nail in the soil, but up till now it has not been proved. The basis of this study is to find the mechanic performance of the discrepancy among different plant roots in reinforcing soil so as to utilize the soft approaches to replace all or partly replace construction measures. Also to find the theoretic basis in strenuous natural restoration and fundamental construction today.

## 2 THE MECHANICAL MODEL OF THE REINFORCEMENT OF SOIL BY ROOTS

The function of root enforcing resistance to impact and corrosion is considered by many learners (Kazuroki, 1990). After observing the physical relationship of planted pine root and soil, Li Yong believes that the physical effective relation of effective root density (<=_1 mm tiny root) contacts closely with the effectiveness of soil-change physically, which can obviously increase soil-stability in water, ratio of macro-tube in soil. It also increases the content of organisms in soil and decreases the density and weight of soil. In this way, it has revealed the performance of soil- impacting resistance enforced by roots (Li, 1993). Liu Guobing (Liu, 1996) made a further study to distinguish the function of reinforcement of soil by roots in three ways: function of series root network, function of root-soil cement and sticking and root biochemical function. On the basis of these, the tissue structure's function of the root itself should be considered as well so that the mechanical model of root network would be considered as the fourth function (Fig. 1).

**Fig. 1 Four mechanical models of soil reinforcement by roots**



**2.1 Four Sorts of Mechanical Model of Reinforcement of Soil by Roots**

*2.1 1 Mechanics of roots*

Mechanics of roots can be defined as the characters of the root function formed against outer force from outside during its growing and developing period and determined by factors, such as: tensile strength, and performance of shear force. Inherited, constructive discrepancy of various roots constitutes distinctive chemical and physical characters of mechanism.

*2.1.2 Linking and force conveying function of root system network*

Roots in any direction compose a root system network, with which the performance and connected ability between networks is determined by the connectedness of the root and soil networks.

*2.1.3 Integrated function of root-soil adhering and cementing acting as a compound power*

On the surface where roots and soil contact with each other, the organic compound performs and acts as the cementing and sticking substance: such as cellulose, protein, polysaccharase, fat, wax, etc. and substances from micro organisms and the alike.

*2.1.4 Biochemical function of root-soil*

In the course of constituting organic compounds, some chemical and biochemical action takes place in the root-soil system. Organic substances, such as polysaccharase, radical–OH, proton–H, act with oxygen on the surface of clay grains and the molecules of organic matter which can be combined or connected by polyvalent cations, such as $Fe^{3+}$, $Ca^{2+}$, $Al^{3+}$ to form a bridge from an organic body to another, so the root-soil compound can be aggregated and perform a compound root-soil system.

**2.2 The Mechanic Analysis in Mechanism of Soil Reinforcement by Root**

Theoretically the power produced on the root mainly includes: extrusion force of crowding out by every root contributed from the top plant weight, adsorptive power of moisture molecular adhering to the surface of roots, sticking and cementing power between root and soil. Also expanding and tensile force of interaction in the root network, frictional resistance between the movement of root and soil, shear and tensile force to the root turned out in the soil sliding, upward force of outtake and uptake substances from outside to inside of the plant root occurs. Therefore, the extrusion press transformed from weight, power of moisture uptake between root and soil, sticking and cementing power, frictional force, tensile force of interaction in the root network and resistance against outside force of the root and shear force above build up of the soil reinforcement mechanics, so, when we judge the mechanic performance of reinforcement of soils by roots, all the above should be considered as key elements.

Since there are less reports on the mechanic performance of herb roots and the research methods for herb roots are simpler compared with those of trees, we take for example, the mechanical performance of several kinds of herbs as follows so to confirm the mechanical performance of roots.

# 3 COMPARISON EXPERIMENTS ON MECHANIC PERFORMANCE OF SOIL-REINFORCEMENT BY ROOT OF SEVERAL HERBS

## 3.1 Materials and Methods of Mechanic Performance of Soil-reinforcement of by Root

*3.1.1 Materials*

Vetiver was collected from the nursery of Nanchang Water Conservancy and Hydropower College on 6 May 2001; Common Cetipede grass, Bahia grass, White Clover, Dallis grass were from the Experimental Station of Forage and Livestock of Jiangxi Province on 5 June 2001.

*3.1.2 Experiment method for testing resistance of root and its tensile strength calculation*

The experiment was carried out according to that introduced by Diti Hengchaovanich, until tensile failure by the force of the maximum resistance was tested using a spring dial gauge for tensile force, and the diameter of root was measured by using a slide caliper rule when tensile failure occurred. The tensile strength was calculated according to the formula "$P= 4\ F/\pi D^2$ (F - maximum tensile force_D - the root diameter when cut off)", with every herb root experiment repeated for 20–28 times.

## 3.2 Result of the Experiment

*3.2.1 Result of the experiment of tensile strength of Vetiver (Table 1)*

**Table 1 Result of the experiment of tensile strength of Vetiver**

| Diameter (mm) | Maximum of tensile force (kg) | Maximum of tensile strength (Mpa) | Diameter (mm) | Maximum of tensile force (kg) | Maximum of tensile strength (Mpa) |
|---|---|---|---|---|---|
| 0.20 | 0.60 | 186.69 | 0.63 | 2.73 | 85.6 |
| 0.35 | 1.20 | 121.90 | 0.62 | 2.80 | 71.4 |
| 0.38 | 1.50 | 129.20 | 0.65 | 2.73 | 63.3 |
| 0.40 | 1.33 | 103.40 | 0.65 | 2.70 | 76.7 |
| 0.40 | 1.50 | 116.70 | 0.66 | 2.74 | 78.2 |
| 0.45 | 1.38 | 97.10 | 0.62 | 2.53 | 81.9 |
| 0.48 | 1.75 | 93.50 | 0.67 | 2.68 | 74.3 |
| 0.55 | 2.23 | 91.70 | 0.62 | 2.63 | 85.2 |
| 0.57 | 2.62 | 100.3 | 0.65 | 2.56 | 75.4 |
| 0.60 | 2.61 | 90.20 | 0.60 | 2.15 | 74.3 |
| 0.63 | 2.66 | 83.4 | 0.70 | 2.95 | 74.9 |
| 0.62 | 2.63 | 85.10 | 1.30 | 4.90 | 36.1 |
| 0.61 | 2.30 | 76.90 | 1.50 | 5.10 | 28.2 |
| 0.62 | 2.48 | 79.00 | 1.70 | 5.30 | 22.9 |

*3.2.2 The result of Bermuda grass and Manila grass* (Table 2)

**Table 2 Result of the experiment of tensile strength of Bermuda grass and Manila grass**

| Bermuda grass | | | Manila grass | | |
|---|---|---|---|---|---|
| Diameter (mm) | Maximum of tensile force (kg) | Maximum of tensile strength (Mpa) | Diameter (mm) | Maximum of tensile force (kg) | Maximum of tensile strength (Mpa) |
| 0.78 | 1.84 | 13.79 | 0.65 | 0.70 | 20.12 |
| 0.85 | 0.92 | 15.85 | 0.90 | 0.75 | 19.05 |
| 0.80 | 0.81 | 15.75 | 0.72 | 0.76 | 18.25 |
| 0.93 | 1.10 | 15.82 | 0.78 | 0.9 | 18.41 |
| 0.90 | 0.82 | 12.61 | 0.75 | 0.75 | 10.40 |
| 1.00 | 0.80 | 9.95 | 0.80 | 0.92 | 17.90 |
| 1.15 | 1.30 | 12.73 | 0.83 | 1.10 | 19.90 |
| 1.17 | 1.25 | 11.37 | 0.87 | 0.93 | 15.30 |
| 1.21 | 1.47 | 12.50 | 0.80 | 0.90 | 17.50 |

*3.2.3 Result of Bahia grass, White Clover (Table 3)*

**Table 3 Results of White Clover, Bahia grass**

| White Clover | | | Bahia grass | | |
|---|---|---|---|---|---|
| Diameter (mm) | Maximum of tensile force (kg) | Maximum of tensile strength (Mpa) | Diameter (mm) | Maximum of tensile force (kg) | Maximum of tensile strength (Mpa) |
| 0.90 | 1.70 | 26.10 | 0.60 | 0.70 | 24.20 |
| 0.90 | 1.75 | 26.80 | 0.65 | 0.73 | 22.40 |
| 0.90 | 1.78 | 25.60 | 0.67 | 0.73 | 20.20 |
| 1.00 | 1.83 | 26.20 | 0.70 | 0.95 | 24.10 |
| 0.80 | 1.56 | 30.30 | 0.75 | 0.95 | 21.00 |
| 0.90 | 1.60 | 25.90 | 0.75 | 0.90 | 15.70 |
| 1.00 | 1.85 | 23.10 | 0.80 | 1.10 | 21.30 |
| 1.20 | 1.40 | 12.10 | 0.83 | 1.00 | 18.10 |
| 1.00 | 1.90 | 23.60 | 0.80 | 1.20 | 18.30 |
| 1.10 | 1.95 | 20.00 | 0.73 | 0.70 | 13.30 |
| 1.20 | 2.10 | 19.70 | 0.84 | 1.22 | 16.90 |

*3.2.4 Result of Late Juncellus and Dallis grass (Table 4)*

**Table 4 Result of Late Juncellus and Dallis grass**

| Late Juncellus | | | Dallis grass | | |
|---|---|---|---|---|---|
| Diameter (mm) | Maximum of tensile force (kg) | Maximum of tensile strength (Mpa) | Diameter (mm) | Maximum of tensile force (kg) | Maximum of tensile strength (Mpa) |
| 0.29 | 0.15 | 29.10 | 0.80 | 1.25 | 24.3 |
| 0.33 | 0.28 | 31.3 | 0.82 | 1.25 | 23.14 |
| 0.35 | 0.25 | 25.4 | 0.84 | 1.29 | 22.70 |
| 0.38 | 0.32 | 27.6 | 0.90 | 1.33 | 20.40 |
| 0.37 | 0.30 | 27.3 | 0.90 | 1.30 | 19.97 |
| 0.40 | 0.28 | 21.8 | 0.93 | 1.30 | 19.40 |
| 0.40 | 0.23 | 19.4 | 0.99 | 1.32 | 18.20 |
| 0.41 | 0.30 | 22.2 | 0.97 | 1.35 | 17.80 |
| 0.41 | 0.28 | 20.3 | 1.00 | 1.30 | 16.20 |
| 0.43 | 0.30 | 20.2 | 1.05 | 1.35 | 15.20 |

*3.2.5 Result of Common Cetipedegrass (Table 5)*

**Table 5 Result of Common Centipedegrass**

| Diameter (mm) | Maximum of tensile force (kg) | Maximum of tensile strength (Mpa) |
|---|---|---|
| 0.6 | 0.85 | 29.3 |
| 0.6 | 0.8 | 27.7 |
| 0.62 | 0.81 | 25.9 |
| 0.65 | 0.9 | 26.5 |
| 0.65 | 1.00 | 29.4 |
| 0.68 | 1.05 | 29.2 |
| 0.70 | 0.95 | 24.1 |
| 0.70 | 1.1 | 27.8 |
| 0.72 | 1.1 | 26.4 |
| 0.75 | 1.2 | 26.5 |

*3.2.6 The anti-pulling force, diameter and tensile strength of root of various herbs (Table 6)*

**Table 6 The anti-pulling force, diameter and tensile strength of root of various herbs**

| Sorts | Average diameter of root (mm) | Average resistance (n) | Average tensile strength (Mpa) |
|---|---|---|---|
| Late Juncellus | 0.38±0.43 | 2.66±0.47 | 24.50±4.2 |
| Dallis grass | 0.92±0.28 | 12.98±0.35 | 19.74±3.00 |
| White Clover | 0.91±0.11 | 12.80±0.59 | 24.64±3.36 |
| Vetiver | 0.66±0.32 | 24.89±1.08 | 85.10±31.2 |
| Common Cetipedegrass | 0.66±0.05 | 9.56±1.33 | 27.30±1.74 |
| Bahio grass | 0.73±0.07 | 8.99±1.99 | 19.23±3.59 |
| Manila grass | 0.77±0.67 | 8.84±1.25 | 17.55±2.85 |
| Bermuda grass | 0.99±0.17 | 10.49±2.65 | 13.45±2.18 |

## 4 DISCUSSION AND CONCLUSION

### 4.1 The Mechanic Property of Herb Roots

The data in Table 6 indicates that roots are composed differently because of their different structures in distinct plants. The mechanical performance of Vetiver reaches 85 Mpa > Common Cetipede grass 27.3 Mpa > White Clover, 24.6 Mpa > Late Juncellus, 24.50 Mpa > Dallis grass, 19.74 Mpa > Bahio grass, 19.23 Mpa > Manila grass, 17.55 Mpa > Bermuda grass, 13.45 Mpa (Cheng and Zhang, 2002). Other studies show that roots of certain trees are elastocut off typically when pulling occurs, such as that of *Populus purdomii*, *Abies Fabri*, and brittle cutoff (Zhu *et al.*, 2002), also *Rhododendron* spp. So the different plant varieties decides the discrepancy of its mechanic performance. Up till now, studies on tensile strength of various roots of distinct plants have been less. It is difficult to find a field study on the mechanical performance of root tensile strengths of various plants compared with other plants.

### 4.2 Mechanics of Reinforcement of Soil by Herb Root in Network

Herbs have no main strong roots comparing to trees. Herbs mainly have fibrous roots or tiny roots (_<= 1 mm), such as Vetiver, which of _<= 1 mm constitute 50-66% (Cheng and Zhang, 2002). In this way, roots can connect fully with the soil, withstand uptake power of water, sticking and cementing power of organisms and inorganic material, frictional force produced from the sliding between roots and soil, moreover, roots can withstand shear turnout from the movement of soil and resistance produced from inside and outside.

**References**

Cheng H, and Zhang XQ. 2002. An experimental study on herb plant root system for strength principle of

soil fixation. Bulletin of Soil and Water Conservation, 22(5): 20-23
Coile TS.1936. Distribution of forest tree roots in North Carolina Piedmont soil. J. For., 35: 247-257
Hengchaovanich D. 1999. 15 years of bioengineering in the wet tropics from A (*Acacia auriculiformis*) to V (*Vetiveria zizanioides*). Proceedings of the First Asia-Pacific Conference on Ground and Water Bioengineering for Erosion Control and Slope Stabilization, Manila, the Philippines. 54-63
Gale MR, and Grigal DE. 1987. Vertical root distribution of northern tree species in relation to successional status. Can J For For, 17: 829-834
Huang CY. 2000. Soil. China Agriculture Press, Beijing
Jackson RB, Canadell J, and Mooney HA. 1996. A global analysis of root distribution for terrestrial biomass. Oecologia, 180: 389-411
Kang SZ. 1994. Theory and application of soil-plant-atmosphere moisture Continuum Transport. Hydraulic and Power Press, Beijing
Kazuroki A, and Masaru I. 1990. Stimulation model for the distribution of tree roots – application to a slope stability model. J. Jap. For. Soc., 72(5): 375-387
Liu GB.1996. A Study on Performance and Erosion-resisting Characteristic in Loess Plateau (Doctor Degree's Paper). Research Institute of Water and Soil Conservation in Northwest China, China Academy of Sciences
Li P, Li SB, *et al*. 2002. Research on root distribution characters of *Robinia Pseudoacacia* on different sides in Weibei, Loess Plateau. Bulletin of Soil and Water Conservation, 22(5): 15-19
Liu JJ. 1998. A review on root ecology of forest trees. Journal of Northwest Forestry College, 13(3): 74-78
Li Y. 1993. A study on the physical effectiveness of improving soil by root of man-planted pine forest. Forest Science, 29(3): 193-198
Lyr H, and Hoffmann G. 1967. Growth rates and growth periodicity of tree roots. Int. Rev. For. Res., 2: 181-236
San JP, and Tao DL. 1992. Overseas researches on tree fine root. Chinese Journal of Ecology, 11(4): 46-49
Song CG, and Zhang XY. 1992. Effect on root by deep tilling. Hubei Forestry Technology, (4): 1-3
Zhao Z, Li P, and Wang NJ. 2002, Distribution of patterns of root of main planting tree species in Weibei Loess Plateau. Chinese Journal of Applied Ecology, 11(1): 37-39
Zhu QK, Chen LH, Zhang DS, *et al.* 2002. Mechanisms of soil-reinforcement by roots in forest ecological in Gongga Mountain. Journal of Beijing Forestry University, 24(4): 64-67

**A Brief Introduction to the First Author**

Cheng Hong, obtained master degree before 1989 and an assistant professor now, is serving in Nanchang Water Conservancy and Hydropower College, and has been studying conservation of soil and water; biological restoration and agronomy. He, with others, has paid much attention to the slope-stability along the highways in Jiangxi Province, has performed several province-level and nation-level research tasks. He has won reward from the Highway Administrative Department of China for his achievements in defining the mechanical properties of herb plant root systems for soil-fixation beside the roads. Furthermore, more than 30 academic papers have been published in this field..